METHOD AND APPARATUS FOR LOCALIZED DELIVERY OF AUDIO SOUND FOR ENHANCED PRIVACY

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority of: (i) U.S. Provisional Patent Application No. 60/462,570, filed April 15, 2003, and entitled "WIRELESS COMMUNICATION SYSTEMS OR DEVICES, HEARING ENHANCEMENT SYSTEMS OR DEVICES, AND METHODS THEREFOR," which is hereby incorporated herein by reference; (ii) U.S. Provisional Patent Application No. 60/469,221, filed May 12, 2003, and entitled "WIRELESS COMMUNICATION SYSTEMS OR DEVICES, HEARING ENHANCEMENT SYSTEMS OR DEVICES, DIRECTIONAL SPEAKER FOR ELECTRONIC DEVICE, PERSONALIZED AUDIO SYSTEMS OR DEVICES, AND METHODS THEREFOR," which is hereby incorporated herein by reference; and (iii) U.S. Provisional Patent Application No. 60/493,441, filed August 8, 2003, and entitled "WIRELESS COMMUNICATION SYSTEMS OR DEVICES, HEARING ENHANCEMENT SYSTEMS OR DEVICES, DIRECTIONAL SPEAKER FOR ELECTRONIC DEVICE, AUDIO SYSTEMS OR DEVICES, WIRELESS AUDIO DELIVERY, AND METHODS THEREFOR," which is hereby incorporated herein by reference.

[0002] This application is also related to: (i) U.S. Patent Application No. _____, filed concurrently, and entitled, "DIRECTIONAL WIRELESS COMMUNICATION SYSTEMS," which is hereby incorporated herein by reference; (ii) U.S. Patent Application No. _____, filed concurrently, and entitled, "DIRECTIONAL HEARING ENHANCEMENT SYSTEMS," which is hereby incorporated herein by reference; (iii) U.S. Patent Application No. _____, filed concurrently, and entitled, "DIRECTIONAL SPEAKER FOR PORTABLE ELECTRONIC DEVICE," which is hereby incorporated herein by reference; and (iv) U.S. Patent Application No. _____, filed concurrently, and entitled, "METHOD AND APPARATUS FOR WIRELESS AUDIO DELIVERY," which is hereby incorporated herein by reference.

FIELD OF THE INVENTION

[0003] The present invention relates to audio systems and, more particularly, to audio output for audio systems with enhanced privacy.

BACKGROUND OF THE INVENTION

[0004] Audio systems provide audio sounds to one or more users. Audio systems, for example, include stereo systems, DVD players, VCRs, and televisions. Typically, these audio systems utilize one or more speakers to provide audio sounds to a wide area. For example, an audio system can be internal to a building (e.g., house) and produce audio sounds from its speakers provided in a particular room. Although the audio sounds are generated in the particular room that contains the speakers, the audio sounds can permeate to other adjoining rooms. The availability of audio sounds anywhere in the particular room and other adjoining rooms is beneficial if other persons in these rooms desire to hear the audio sounds. Unfortunately, in numerous occasions, the other persons in these rooms can find the audio output to be quite annoying. In effect, to these others, the unwanted audio sounds are a form of noise pollution.

[0005] Today, there are no satisfactory solutions to reduce such noise pollution. The person (or persons) desirous of hearing the audio sounds can reduce the volume of the audio sounds or close openings (e.g., doors) to the adjoining rooms. These approaches are of limited usefulness as audio sounds can pass through doors and walls. Also, reducing volume may not be acceptable by the person desiring to hear the audio sounds. Alternatively, headsets, each with one or a pair of speakers, can be used. However, wearing a headset can create its own problem. For example, wearing a headset substantially limits the user's ability to hear other sounds. When more than a single person wants to hear the audio sounds, often they also prefer to simultaneously interact with each other, or otherwise hear other sounds. Moreover, the use of a headset usually means only one person can hear the audio sounds.

[0006] Thus, there is a need for improved approaches to providing audio sounds to desirous persons while reducing disturbance to other persons not desirous of hearing the audio sounds.

SUMMARY OF THE INVENTION

[0007] The invention pertains to a directional audio delivery device for an audio system. The audio delivery device provides directional delivery of audio output for the audio system. The generated audio output is substantially confined in one or more beams, each with a beam width. The output is targeted to one or more persons who would like to hear the audio output. In one embodiment, these one or more persons can also change a number of attributes of each beam, such as the direction and the width of, and the distance covered by, the beam(s), as desired. Consequently, other persons not desirous of hearing the audio output, can only hear a substantially lower level of the audio output, and thus are less disturbed by the unwanted audio sounds.

[0008] The audio system with the directional audio delivery device can be known as a directional audio apparatus. In one embodiment, the audio delivery device includes a directional speaker. In one exemplary configuration, the directional audio delivery device is in a set-top box that is electrically coupled to the audio system. In another exemplary configuration, the audio delivery device is in the audio system.

[0009] In one embodiment, a number of attributes of the audio outputs can be adjusted. For example, the propagation direction of the beam can be altered by changing the position of the speaker. As another example, the speaker can have a curved surface, which can also be segmented, to control the beam width and/or the beam direction. The audio output is embedded in or generated from ultrasonic signals. The frequency of the ultrasonic signals can be adjusted continuously or discreetly to modify the width of the beam and the distance covered by the beam. The speaker can have many speaker elements, such as bimorphs. The phases to the elements can be controlled to, for example, change the beam width. In one embodiment, these adjustments can be activated by a user using a remote control. In another embodiment, adjustments can be made automatically based on, for example, the location of the user. The output from the directional speaker can be confined in an enclosure to increase the path

length of the beam before emitting into free space. This approach can reduce potential hazards, if any, of high power ultrasonic signals. Also, more than one directional speaker can be used to create stereo effects.

[0010] The invention can be implemented in numerous ways, including as a method, system, device, apparatus, and a computer readable medium.

[0011] Other aspects and advantages of the invention will become apparent from the following detailed description taken in conjunction with the accompanying drawings which illustrate, by way of example, the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] The invention will be readily understood by the following detailed description in conjunction with the accompanying drawings, wherein like reference numerals designate like structural elements, and in which:

[0013] FIG. 1 is a block diagram of a directional audio delivery device coupled to an audio system according to one embodiment of the invention.

[0014] FIG. 2A is a block diagram of a directional audio delivery device according to one embodiment of the invention.

[0015] FIG. 2B is a block diagram of a directional audio delivery device according to another embodiment of the invention.

[0016] FIG. 3A is a diagram illustrating a representative arrangement suitable for use by different embodiments of the invention.

[0017] FIG. 3B is a diagram of a representative building layout illustrating one application of the present invention.

[0018] FIG. 4 is a flow diagram of directional audio delivery processing according to an embodiment of the invention.

[0019] FIG. 5 shows examples of attributes of the constrained audio output according to the invention.

[0020] FIG. 6 is another representative building layout illustrating one application of the present invention.

[0021] FIG. 7 is a flow diagram of directional audio delivery processing according to another embodiment of the invention.

[0022] FIG. 8A is a flow diagram of directional audio delivery processing according to yet another embodiment of the invention.

[0023] FIG. 8B is a flow diagram of an environmental accommodation process according to one embodiment of the invention.

[0024] FIG. 8C is a flow diagram of audio personalization process according to one embodiment of the invention.

[0025] FIG. 9A is a perspective diagram of an ultrasonic transducer according to one embodiment of the invention.

[0026] FIG. 9B is a diagram that illustrates the ultrasonic transducer with its beam being produced for audio output according to an embodiment of the invention.

[0027] FIGs. 9C-9D illustrate two embodiments of the invention where the directional speakers are segmented.

[0028] FIGs. 9E-9G shows changes in beam width based on different carrier frequencies according to an embodiment of the present invention.

[0029] FIGs. 10A-10B are diagrams of two embodiments of the invention where the directional speakers have curved surfaces to expand the beam.

[0030] FIG. 10C shows beam expansion based on a convex reflector according to an embodiment of the invention.

[0031] FIGs. 11A-11B show two embodiments of the invention whose directional speakers have curved surfaces that are segmented.

[0032] FIGs. 12A and 12B are perspective diagrams of audio systems with directional audio delivery devices in a set-top-box environment according to different embodiments of the present invention.

[0033] FIG. 13 is a perspective diagram of a remote control device according to one embodiment of the invention.

[0034] FIGs. 14A-14B show two embodiments of the invention with directional audio delivery devices that allow ultrasonic signals to bounce back and forth before emitting into free space.

[0035] FIG. 15 shows two directional audio delivery devices spaced apart to generate stereo effects according to one embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION.

[0036] The invention pertains to a directional audio delivery device for an audio system. The audio system can be a stereo system, a DVD player, a compact disc player, a music amplifier or a musical instrument, a VCR, a television, a home-entertainment system, or other audio system. The audio system typically delivers audio output based on, or pertaining to, certain audio signals. These audio signals can be generated by the audio system, or they can be transmitted to and received by the audio system. The reception by the audio system can be wireless or wireline, such as through cables. Without the directional audio delivery device, the audio system produces audio sound for the benefit of any persons in its general vicinity. The directional audio delivery device converts the audio signals into directional audio output that is substantially confined within a beam having a beam width. The directional audio output is targeted to one or more persons who would like to hear the audio output. In one embodiment, these one or more persons can also control a number of attributes of the beam. Other persons in the same vicinity who are not desirous of hearing the audio output, would only hear a substantially lower level of the audio output. Hence, they are less disturbed by the unwanted audio sounds.

[0037] The audio system with its corresponding directional audio delivery device can be known as a directional audio apparatus. The directional device can be incorporated into the audio system, or can be confined in a separate housing, such as in a set-top box. The set-top box can be wired or wirelessly coupled to the audio system. In this embodiment, if the corresponding audio signals are not generated by the audio system, but are received externally, the audio signals can be received either by the set-top box or by the audio system.

[0038] Embodiments of the invention are discussed below with reference to FIGs. 1 – 15. However, those skilled in the art will readily appreciate that the detailed description given herein with respect to these figures is for explanatory purposes as the invention extends beyond these limited embodiments.

[0039] FIG. 1 is a block diagram of a directional audio apparatus 100 with an audio system 102 and a directional audio delivery device 104, according to one embodiment of the invention.

[0040] FIG. 2A is a block diagram of a directional audio delivery device 200 according to one embodiment of the invention. The directional audio delivery device 200 is, for example, suitable for use as the directional audio delivery device 104 illustrated in FIG.1.

[0041] The directional audio delivery device 200 includes audio conversion circuitry 202 and a directional speaker 204. The audio conversion circuitry 202 receives audio signals (Audio-In). The reception can be from the audio system 102, or can be from another device. The audio signals can be, for example, electrical signals from the audio system 102, or audio waves wirelessly transmitted to be received by the audio conversion circuitry 202. The received audio signals can then be pre-processed, and are then converted into ultrasonic signals that are supplied to the directional speaker 204. In one embodiment, the directional speaker 204 is an ultrasonic speaker that produces ultrasonic output to generate audio output. The ultrasonic output carries the audio output to be delivered in a directionally constrained manner. The directional speaker 204 thus allows the audio output to be directionally constrained and delivered to desired areas.

[0042] FIG. 2B is a block diagram of a directional audio delivery device 220 according to another embodiment of the invention. The directional audio delivery device 220 is, for example, suitable for use as the directional audio delivery device 104 illustrated in FIG. 1.

[0043] The directional audio delivery device 220 includes audio conversion circuitry 222, a beam-attribute control unit 224 and a directional speaker 226. The audio conversion circuitry 222 converts the received audio signals into ultrasonic signals. The directional speaker 226 receives the ultrasonic signals and produces an audio output. The beam-attribute control unit 224 controls one or more attributes of the audio output.

[0044] One attribute can be the beam direction. The beam-attribute control unit 224 receives a beam attribute input, which in this example is related to the direction of the beam. This can be known as a direction input. The direction input provides information to the beam-attribute control unit 224 pertaining to a propagation direction of the ultrasonic output produced by the directional speaker 226. The direction input can be a position reference, such as a position for the directional speaker 226 (relative to its housing), the position of a person desirous of hearing the audio sound, or the position of an external electronic device (e.g., remote controller). Hence, the beam-attribute control unit 224 receives the direction input and determines the direction of the audio output.

[0045] Another attribute can be the desired distance to be traveled by the beam. This can be known as a distance input. In one embodiment, the ultrasonic frequency of the audio output can be adjusted. By controlling the ultrasonic frequency, the desired distance traveled by the beam can be adjusted. This will be further explained below. Thus, with the appropriate control signals, the directional speaker 226 generates the desired audio output accordingly.

[0046] FIG. 3A is a diagram illustrating a representative arrangement 300 suitable for use with the invention. The representative arrangement 300 uses a directional audio apparatus 302 to deliver audio output, which can be an ultrasonic cone 304 (or beam) of ultrasonic output towards a first user (user-1). The directional audio apparatus 302 can, for example, be the directional audio apparatus 100, using any implementation of a directional audio delivery device. Note that in the representative arrangement 300, a second user (user-2) and a third user (user-3) are also in the vicinity of the directional audio apparatus 302. However, in this example, it is assumed that only the first user (and not the second and third users) is desirous of hearing the audio sound. As a result, the directional audio apparatus 302 produces the ultrasonic output in a directionally constrained manner such that its cone 304 (or beam) is directed towards the first user (user-1). After the ultrasonic output is mixed or demodulated in air, the resultant audio sound is delivered to the first user (user-1). Any resultant audio sound received by the second user (user-2) and the third user (user-3) is at a

significantly lower level (e.g., not heard). Consequently, the second user (user-2) and the third user (user-3) are not disturbed by the audio output that is being heard by the first user (user-1).

[0047] Another way to control the audio output level to be received by other users is through the distance input. By controlling the distance the ultrasonic output travels, the directional audio delivery device 302 can minimize the audio output that might reach other persons (i) positioned behind the first user (user-1) not shown in the figure, or (ii) positioned at a location that would receive the audio output upon its reflection from surfaces behind the first user (user-1).

[0048] FIG. 3B is a diagram of a representative building layout 320 illustrating one application of the present invention. The representative building layout 320 is used to illustrate how a directional audio apparatus 328 according to the invention can be utilized. The representative building layout 320 includes a first room 322, a second room 324 and a third room 326. The first room 322 can, for example, be a family room. The first room 322 includes a directional audio apparatus 328. A first user (u-1), a second user (u-2) and a third user (u-3) are in the first room 322. The directional audio apparatus 328 can deliver audio sound in a directionally confined manner. The directional audio apparatus 328 can, for example, be the directional audio apparatus 100, using any implementation of a directional audio delivery device in the present invention.

[0049] As shown in FIG. 3B, the directional audio apparatus 328 delivers a constrained cone 330 (beam) of audio output or sound towards the first user (u-1). Note that the audio output is substantially constrained within the cone 330. As a result, the second user (u-2) and the third user (u-3) do not hear the audio output produced by the directional audio apparatus 328 in any significant way. Some of the sound from the cone 330 might be reflected or dispersed off a rear wall, and received by the second and third users. If so, the sound would have attenuated to a substantially lower level. In one embodiment, the distance covered by the cone 330 of sound can be adjusted. In another embodiment, the breath of the cone 330 can be adjusted.

[0050] FIG. 4 is a flow diagram of directional audio delivery processing 400 according to an embodiment of the invention. The directional audio delivery processing 400 is, for example, performed by a directional audio delivery device, such as the directional audio delivery device 104 illustrated in FIG. 1. More particularly, the directional audio delivery processing 400 is particularly suitable for use by the directional audio delivery device 220 illustrated in FIG. 2B.

[0051] The directional audio delivery processing 400 initially receives 402 audio signals for directional delivery. The audio signals can be supplied by an audio system. In addition, a beam attribute input is received 404. As previously noted, the beam attribute input is a reference or indication of one or more attributes regarding the audio output to be delivered. After the beam attribute input has been received 404, one or more attributes of the beam are determined 406 based on the attribute input. If the attribute pertains to the direction of the beam, the input can set the constrained delivery direction of the beam. The constrained delivery direction is the direction that the output is delivered. The audio signals that were received are converted 408 to ultrasonic signals with appropriate attributes, which may include one or more of the determined attributes. Finally, the directional speaker is driven 410 to generate ultrasonic output again with appropriate attributes. In the case where the direction of the beam is set, the ultrasonic output is directed in the constrained delivery direction. Following the operation 410, the directional audio delivery processing 400 is complete and ends. Note that the constrained delivery direction can be altered dynamically or periodically, if so desired.

[0052] FIG. 5 shows examples of beam attributes 500 of the constrained audio output according to the invention. These beam attributes 500 can be provided either automatically, such as periodically, or manually, such as at the request of a user. The attributes can be for the beam-attribute control unit 224. One attribute, which has been previously described, is the direction 502 of the beam. Another attribute can be the beam width 504. In other words, the width of the ultrasonic output can be controlled. In one embodiment, the beam width is the width of the beam at the desired position. For example, if the desired

location is 10 feet directly in front of the directional audio apparatus, the beam width can be the width of the beam at that location. In another embodiment, the width 504 of the beam is defined as the width of the beam at its full-width-half-max (FWHM) position.

[0053] The desired distance 506 to be covered by the beam can be set. In one embodiment, the rate of attenuation of the ultrasonic output/audio output can be controlled to set the desired distance. In another embodiment, the volume or amplification of the beam can be changed to control the distance to be covered. Through controlling the desired distance, other persons in the vicinity of the person to be receiving the audio signals (but not adjacent thereto) would hear little or no sound. If sound were heard by such other persons, its sound level would have been substantially attenuated (e.g., any sound heard would be faint and likely not discernable).

[0054] There are also other types of beam attribute inputs. For example, the inputs can be the position 508, and the size 510 of the beam. The position input can pertain to the position of a person desirous of hearing the audio sound, or the position of an electronic device (e.g., remote controller). Hence, the beam-attribute control unit 224 receives the beam position input and the beam size input, and then determines how to drive the directional speaker to output the audio sound to a specific position with the appropriate beam width. Then, the beam-attribute control unit 226 produces drive signals, such as ultrasonic signals and other control signals. The drive signals controls the directional speaker 506 to generate the ultrasonic output towards a certain position with a particular beam size.

[0055] There can be more than one beam. Hence, one attribute of the beam is the number 512 of beams present. Multiple beams can be utilized, such that multiple persons are able to receive the audio signals via the ultrasonic output by the directional speaker (or a plurality of directional speakers). Each beam can have its own attributes.

[0056] There can also be a dual mode operation 514 having a directional mode and a normal mode. The directional audio apparatus can include a normal

speaker (e.g., substantially omni-directional speaker). There are situations where a user would prefer the audio output to be heard by every one in a room, for example. Under this situation, the user can deactivate the directional delivery mechanism of the apparatus, or can allow the directional audio apparatus to channel the audio signals to the normal speaker to generate the audio output. In one embodiment, a normal speaker generates its audio output based on audio signals, without the need for generating ultrasonic outputs. However, a directional speaker requires ultrasonic signals to generate its audio output.

[0057] FIG. 6 is another representative building layout 600 illustrating an application of the present invention. The representative building layout 600 is generally similar to the representative building layout 320 illustrated in FIG. 3B. In this example, the representative building layout 600 includes a first room 602, a second room 604 and a third room 606. Although a first user (u-1), a second user (u-2) and a third user (u-3) are all within the first room 602, only the first user (u-1) and the second user (u-2) want to hear the audio sound from an audio system. Accordingly, the first room 602 includes a directional audio apparatus 608 to output a cone 610 (or beam) of ultrasonic output towards the first user (u-1) and the second user (u-2). Note that the cone 610 can have a greater width or footprint than does the cone 330 illustrated in FIG. 3B so that it substantially encompasses both the first user (u-1) and the second user (u-2). Nevertheless, the third user (u-3) is not proximate to the cone 610; hence, the third user (u-3) is not significantly disturbed by the audio sound that the first and second users hear by way of the ultrasonic output from the directional audio apparatus 608.

[0058] Note that the cone 610 or the beam does not have to propagate directly to the first (u-1) and the second user (u-2). In one embodiment, the beam can propagate towards the ceiling of the building, which reflects the beam back towards the floor to be received by the users. One advantage of such an embodiment is to lengthen the propagation distance to broaden the width of the beam when it reaches the users. Another feature of this embodiment is that the users do not have to be in the line-of-sight of the directional audio apparatus.

[0059] FIG. 7 is a flow diagram of directional audio delivery processing 700 according to another embodiment of the invention. The directional audio delivery processing 700 is, for example, performed by the directional audio delivery device 104 illustrated in FIG. 1. More particularly, the directional audio delivery processing 700 is particularly suitable for use by the directional audio delivery device 220 illustrated in FIG. 2B.

[0060] The directional audio delivery processing 700 receives 702 audio signals for directional delivery. The audio signals are provided by an audio system. In addition, two beam attribute inputs are received, and they are a position input 704 and a beam size input 706. Next, the directional audio delivery processing 700 determines 708 a delivery direction and a beam size based on the position input and the beam size input. The desired distance to be covered by the beam can also be determined. The audio signals are then converted 710 to ultrasonic signals, with the appropriate attributes. For example, the frequency and/or the power level of the ultrasonic signals can be generated to set the desired travel distance of the beam. Thereafter, a directional speaker (e.g., ultrasonic speaker) is driven 712 to generate ultrasonic output in accordance with, for example, the delivery direction and the beam size. In other words, when driven 712, the directional speaker produces ultrasonic output (that carries the audio sound) towards a certain position, with a certain beam size at that position. In one embodiment, the ultrasonic signals are dependent on the audio signals, and the delivery direction and the beam size are used to control the directional speaker. In another embodiment, the ultrasonic signals can be dependent on not only the audio signals but also the delivery direction and the beam size. Following the operation 712, the directional audio delivery processing 700 is complete and ends.

[0061] FIG. 8A is a flow diagram of directional audio delivery processing 800 according to yet another embodiment of the invention. The directional audio delivery processing 800 is, for example, suitable for use by the directional audio delivery device 104 illustrated in FIG. 1. More particularly, the directional audio delivery processing 800 is particularly suitable for use by the directional audio

delivery device 220 illustrated in FIG. 2B, with the beam attribute inputs being beam position and beam size received from a remote device.

[0062] The directional audio delivery processing 800 initially activates a directional audio apparatus that is capable of constrained directional delivery of audio sound. A decision 804 determines whether a beam attribute input has been received. Here, in accordance with one embodiment, the audio apparatus has associated with it a remote control device, and the remote control device can provide the beam attributes. Typically, the remote control device enables a user positioned remotely (e.g., but in line-of-sight) to change settings or characteristics of the audio apparatus. One beam attribute is the desired location of the beam. Another attribute is the beam size. According to the invention, a user of the audio apparatus might hold the remote control device and signal to the directional audio apparatus a position reference. This can be done by the user, for example, through selecting a button on the remote control device. This button can be the same button for setting the beam size because in transmitting beam size information, location signals can be relayed as well. The beam size can be signaled in a variety of ways, such as via a button, dial or key press, using the remote control device. When the decision 804 determines that no attributes have been received from the remote control device, the decision 804 can just wait for an input.

[0063] When the decision 804 determines that a beam attribute input has been received from the remote control device, control signals for the directional speaker are determined 806 based on the attribute received. If the attribute is a reference position, a delivery direction can be determined based on the position reference. If the attribute is for a beam size adjustment, control signals for setting a specific beam size are determined. Then, based on the control signals determined, the desired ultrasonic output that is constrained is produced 812.

[0064] Next, a decision 814 determines whether there are additional attribute inputs. For example, an additional attribute input can be provided to incrementally increase or decrease the beam size. The user can adjust the beam size, hear the effect and then further adjust it, in an iterative manner.

When the decision 814 determines that there are additional attribute inputs, appropriate control signals are determined 806 to adjust the ultrasonic output accordingly. When the decision 814 determines that there are no additional inputs, the directional audio apparatus can be deactivated. When the decision 816 determines that the audio system is not to be deactivated, then the directional audio delivery processing 800 returns to continuously output the constrained audio output. On the other hand, when the decision 816 determines that the directional audio apparatus is to be deactivated, then the directional audio delivery processing 800 is complete and ends.

[0065] Besides directionally constraining audio sound that is to be delivered to a user, the audio sound can optionally be additionally altered or modified in view of the user's hearing characteristics or preferences, or in view of the audio conditions in the vicinity of the user.

[0066] FIG. 8B is a flow diagram of an environmental accommodation process 840 according to one embodiment of the invention. The environmental accommodation process 840 determines 842 environmental characteristics. In one implementation, the environmental characteristics can pertain to measured sound (e.g., noise) levels at the vicinity of the user. The sound levels can be measured by a pickup device (e.g., microphone) at the vicinity of the user. The pickup device can be at the remote device held by the user. In another implementation, the environmental characteristics can pertain to estimated sound (e.g., noise) levels at the vicinity of the user. The sound levels at the vicinity of the user can be estimated based on a position of the user/device and/or the estimated sound level for the particular environment. For example, sound level in a department store is higher than the sound level in the wilderness. The position of the user can, for example, be determined by Global Positioning System (GPS) or other triangulation techniques, such as based on infrared, radio-frequency or ultrasound frequencies with at least three non-collinear receiving points. There can be a database with information regarding typical sound levels at different locations. The database can be accessed to retrieve the estimated sound level based on the specific location.

[0067] After the environmental accommodation process 840 determines 842 the environmental characteristics, the audio signals are modified based on the environmental characteristics. For example, if the user were in an area with a lot of noise (e.g., ambient noise), such as at a confined space with various persons or where construction noise is present, the audio signals could be processed to attempt to suppress the unwanted noise, and/or the audio signals (e.g., in a desired frequency range) could be amplified. One approach to suppress the unwanted noise is to introduce audio outputs that are opposite in phase to the unwanted noise so as to cancel the noise. In the case of amplification, if noise levels are excessive, the audio output might not be amplified to cover the noise because the user might not be able to safely hear the desired audio output. In other words, there can be a limit to the amount of amplification and there can be negative amplification on the audio output (even complete blockage) when excessive noise levels are present. Noise suppression and amplification can be achieved through conventional digital signal processing, amplification and/or filtering techniques. The environmental accommodation process 840 can, for example, be performed periodically or if there is a break in audio signals for more than a preset amount of time. The break may signify that there is a new audio stream.

[0068] A user might have a hearing profile that contains the user's hearing characteristics. The audio sound provided to the user can optionally be customized or personalized to the user by altering or modifying the audio signals in view of the user's hearing characteristics. By customizing or personalizing the audio signals to the user, the audio output can be enhanced for the benefit or enjoyment of the user.

[0069] FIG. 8C is a flow diagram of an audio personalization process 860 according to one embodiment of the invention. The audio personalization process 860 retrieves 862 an audio profile associated with the user. The hearing profile contains information that specifies the user's hearing characteristics. For example, the hearing characteristics may have been acquired by the user taking

a hearing test. Then, the audio signals are modified 864 or pre-processed based on the audio profile associated with the user.

[0070] The hearing profile can be supplied to a directional audio delivery device performing the personalization process 860 in a variety of different ways. For example, the audio profile can be electronically provided to the directional audio delivery device through a network. As another example, the audio profile can be provided to the directional audio delivery device by way of a removable data storage device (e.g., memory card). Additional details on audio profiles and personalization to enhance hearing can be found in U.S. Patent Application No. ______, filed ___ and entitled "DIRECTIONAL HEARING ENHANCEMENT SYSTEMS", which is hereby incorporated herein by reference.

[0071] The environmental accommodation process 840 and/or the audio personalization process 860 can optionally be performed together with any of the directional audio delivery devices or processes discussed above. For example, the environmental accommodation process 840 and/or the audio personalization process 860 can optionally be performed together with any of the directional audio delivery processes 400, 700 or 800 embodiments discussed above with respect to FIGs. 4, 7 and 8. The environmental accommodation process 840 and/or the audio personalization process 860 typically would precede the operation 408 in FIG. 4, the operation 710 in FIG. 7 and/or the operation 812 in FIG. 8A.

[0072] FIG. 9A is a perspective diagram of an ultrasonic transducer 900 according to one embodiment of the invention. The ultrasonic transducer 900 can implement the directional speakers discussed herein. The ultrasonic transducer 900 produces the ultrasonic output utilized as noted above. In one embodiment, the ultrasonic transducer 900 includes a plurality of resonating tubes 902 covered by a piezoelectric thin-film, such as PVDF, that is under tension. When the film is driven by a voltage at specific frequencies, the structure will resonate to produce the ultrasonic output. Additional details on the ultrasonic transducer 900 can be found in U.S. Patent Application No. ______,

filed ___ and entitled "DIRECTIONAL WIRELESS COMMUNICATION SYSTEMS", which is hereby incorporated herein by reference.

[0073] Mathematically, the resonance frequency f of each eigen mode (n,s) of a circular membrane can be represented by:

[0074] $f(n,s) = \alpha(n,s)/(2\pi a) * \sqrt{(S/m)}$

[0075] where

[0076] a is the radius of the circular membrane,

[0077] S is the uniform tension per unit length of boundary, and

[0078] M is the mass of the membrane per unit area.

[0079] For different eigen modes of the tube structure shown in FIG. 9A,

[0080] $\alpha(0,0) = 2.4$

[0081] $\alpha(0,1) = 5.52$

[0082] $\alpha(0,2) = 8.65$

[0083] . . .

[0084] Assume $\alpha(0,0)$ to be the fundamental resonance frequency, and is set to be at 50 kHz. Then, $\alpha(0,1)$ is 115 kHz, and $\alpha(0,2)$ is 180 kHz etc. The n = 0 modes are all axisymmetric modes. In one embodiment, by driving the thin-film at the appropriate frequency, such as at any of the axisymmetric mode frequencies, the structure resonates, generating ultrasonic waves at that frequency.

[0085] Instead of using a membrane over the resonating tubes, in another embodiment, the ultrasonic transducer is made of a number of speaker elements, such as unimorph, bimorph or other types of multilayer piezoelectric emitting elements. The elements can be mounted on a solid surface to form an array. These emitters can operate at a wide continuous range of frequencies, such as from 40 to 200 kHz.

[0086] One embodiment to control the distance of propagation of the ultrasonic output is by changing the carrier frequency, such as from 40 to 200 kHz. Frequencies in the range of 200 kHz have much higher acoustic attenuation in air than frequencies around 40 kHz. Thus, the ultrasonic output

can be attenuated at a much faster rate at higher frequencies, reducing the potential risk of ultrasonic hazard to health, if any. Note that the degree of attenuation can be changed continuously, such as based on multi-layer piezoelectric thin-film devices by continuously changing the carrier frequency. In another embodiment, the degree of isolation can be changed more discreetly, such as going from one eigen mode to another eigen mode of the tube resonators with piezoelectric membranes.

[0087] FIG. 9B is a diagram that illustrates the ultrasonic transducer 900 generating its beam 904 of ultrasonic output.

[0088] The width of the beam 904 can be varied in a variety of different ways. For example, a reduced area or one segment of the transducer 900 can be used to decrease the width of the beam 904. In the case of a membrane over resonating tubes, there can be two concentric membranes, an inner one 910 and an outer one 912, as shown in FIG. 9C. One can turn on the inner one only, or both at the same time with the same frequency, to control the beam width. FIG. 9D illustrates another embodiment 914, with the transducer segmented into four quadrants. The membrane for each quadrant can be individually controlled. They can be turned on individually, or in any combination to control the width of the beam. In the case of directional speakers using an array of bimorph elements, reduction of the number of elements can be used to reduce the size of the beam width. Another approach is to activate elements within specific segments to control the beam width.

[0089] In yet another embodiment, the width of the beam can be broadened by increasing the frequency of the ultrasonic output. To illustrate this embodiment, the dimensions of the directional speaker are made to be much larger than the ultrasonic wavelengths. As a result, beam divergence based on aperture diffraction is relatively small. One reason for the increase in beam width in this embodiment is due to the increase in attenuation as a function of the ultrasonic frequency. Examples are shown in FIGs. 9E-9G, with the ultrasonic frequencies being 40 kHz, 100 kHz and 200 kHz, respectively. These figures illustrate the audio output beam patterns computed by integrating the non-linear

KZK equation based on an audio frequency at 1 kHz. The emitting surface of the directional speaker is assumed to be a planar surface of 20 cm by 10 cm. Such equations are described, for example, in "Quasi-plane waves in the nonlinear acoustics of confined beams," by E.A.Zabolotskaya and R.V.Khokhov, which appeared in Sov. Phys. Acoust., Vol.15, pp.35-40, 1969; and "Equations of nonlinear acoustics," by V.P.Kuznetsov, which appeared in Sov. Phys. Acoust., Vol.16, pp.467-470, 1971.

[0090] In the examples shown in FIGs. 9E-9G, the acoustic attenuations are assumed to be 0.2 per meter for 40 kHz, 0.5 per meter for 100 kHz and 1.0 per meter for 200 kHz. The beam patterns are calculated at a distance of 4 m away from the emitting surface and normal to the axis of propagation. The x-axis of the figures indicates the distance of the test point from the axis (from -2 m to 2 m), while the y-axis of the figures indicates the calculated acoustic pressure in dB SPL of the audio output at the test point. The emitted power for the three examples are normalized so that the received power for the three audio outputs on-axis are roughly the same (e.g. at 56 dB SPL 4 m away). Comparing the figures, one can see that the lowest carrier frequency (40 kHz in FIG. 9E) gives the narrowest beam and the highest carrier frequency (200 kHz in FIG. 9G) gives the widest beam. One explanation can be that higher acoustic attenuation reduces the length of the virtual array of speaker elements, which tends to broaden the beam pattern. Anyway, in this embodiment, a lower carrier frequency provides better beam isolation, with privacy enhanced.

[0091] As explained, the audio output is in a constrained beam for enhanced privacy. Sometimes, although a user would not want to disturb other people in the immediate neighborhood, the user may want the beam to be wider or more divergent. A couple may be sitting together to watch a movie. Their enjoyment would be reduced if one of them cannot hear the movie because the beam is too narrow. In a number of embodiments to be described below, the width of the beam can be expanded in a controlled manner based on curved structural surfaces or other phase-modifying beam forming techniques.

[0092] FIG. 10A illustrates one approach to diverge the beam based on an ultrasonic speaker with a convex emitting surface. The surface can be structurally curved in a convex manner to produce a diverging beam. The embodiment shown in FIG. 10A has a spherical-shaped ultrasonic speaker 1000, or an ultrasonic speaker whose emitting surface of ultrasonic output is spherical in shape. In the spherical arrangement 1000, a spherical surface 1002 has a plurality of ultrasonic elements 1004 affixed (e.g. bimorphs) or integral thereto. The ultrasonic speaker with a spherical surface 1002 forms a spherical emitter that outputs an ultrasonic output within a cone (or beam) 1006. Although the cone will normally diverge due to the curvature of the spherical surface 1002, the cone 1006 remains directionally constrained.

[0093] In an embodiment where speaker elements are affixed or coupled to a spherical surface, each ultrasonic element 1004 is oriented to point towards the center of a sphere of which the spherical surface 1002 is a part of. In one embodiment where elements are integral to a spherical or curved surface, there can be a plurality of resonating tubes 1026, as shown in FIG. 10B. The length-wise axis of each resonating cavity 1026 points to the center of the sphere of which the spherical surface 1002 is a part of. The resonating tubes 1026 can be formed in a single fabrication step so as to ensure their uniformity. This can be done, for example, by form-pressing all of the holes at the same time.

[0094] In the embodiment where the ultrasonic speaker includes resonating tubes, there is a thin-film piezoelectric membrane mounted on one side of the tubes. It can be either on the convex side 1034 or the concave side 1036 of a surface 1010, as shown in FIG. 10B. In the embodiment of the surface 1010 shown in FIG. 10B, the membrane is assumed to be mounted on the concave side 1036. After the membrane is mounted, a vacuum can be formed to have the membrane press onto the tubes. Voltages can be applied to the membrane to generate the ultrasonic output. This creates an emitting surface that is structurally curved in a concave manner. As shown in FIG. 10B, the beam produced 1040 initially converges and then diverges.

[0095] The degree of divergence is determined, for example, by the curvature of the surface 1002 or 1036. In one embodiment, referring back to FIG. 10A, the radius of the spherical surface is about 40 cm, its height 1007 is about 10 cm and its width 1008 is about 20 cm.

[0096] Diverging beams can also be generated even if the emitting surface of the ultrasonic speaker is a planar surface. For example, as shown in FIG. 10C, a convex reflector 1050 can be used to reflect the beam 904 into a diverging beam 918 (and thus with an increased beam width). In this embodiment, the ultrasonic speaker can be defined to include the convex reflector 1050.

[0097] Another way to modify the shape of a beam, so as to diverge or converge the beam, is through controlling phases. In one embodiment, the directional speaker includes a number of speaker elements, such as bimorphs. The phase shifts to individual elements of the speaker can be individually controlled. With the appropriate phase shift, one can generate ultrasonic outputs with a quadratic phase wave-front to produce a converging or diverging beam. For example, the phase of each emitting element is modified by $k*r^2 / (2F_0)$, where (a) r is the radial distance of the emitting element from the point where the diverging beam seems to originate from, (b) F_0 is the desired focal distance, (c) k -- the propagation constant of the audio frequency f -- is equal to $2\pi f / c_0$, where c_0 is the acoustic velocity.

[0098] In yet another example, beam width can be changed by modifying the focal length or the focus of the beam, or by de-focusing the beam. This can be done electronically through adjusting the relative phases of the ultrasonic signals exciting different directional speaker elements.

[0099] Curved surfaces can also be segmented to control the beam width or beam propagating direction. FIG. 11A illustrates a cylindrical-shaped ultrasonic speaker 1100 according to an embodiment of the invention. In this embodiment, the emitting surface of the directional speaker is cylindrical in shape and is segmented. In the cylindrical arrangement 1100, a cylindrical surface 1102 has a plurality of ultrasonic elements 1104 affixed (e.g., bimorphs) or

integral thereto (e.g., tubes covered by a membrane). Each ultrasonic element 1104 is oriented horizontally on, but pointed towards the center line of, a cylinder of which the cylindrical surface 1102 is a part of. In the case of elements being resonating tubes, the length-wise axis of each tube is horizontal and points towards the center line of the cylinder of which the cylindrical surface 1102 is a part of. Again, although the cone of ultrasonic output 1106 will normally diverge, the cone remains directionally constrained. In one embodiment, the radius of the cylindrical surface 1102 of the cylinder-shaped ultrasonic speaker 1100 is about 40 cm, its height 1110 is about 10 cm and its width 1112 is about 20 cm.

[00100] In the speaker embodiment shown in FIG. 11A, the cylindrical surface 1102 can be segmented, such as into three separate controllable segments 1105, 1107 and 1109. Each of the segments can be selectably activated to control the direction and/or width of the ultrasonic output. For the embodiment where the speaker is made of tubes covered by membranes, each segment can have its own membrane. To generate the widest beam, all three segments are activated simultaneously by signals with substantially the same frequencies, phases and amplitudes.

[00101] FIG. 11B shows another example of segmenting the emitting surface according to the present invention. A transducer surface 1140 has a curved configuration 1142 that includes four controllable segments 1144, 1146, 1148 and 1150. Each of the segments of the curved configuration 1142 can be selectably activated to control the direction and/or width of the ultrasonic output. For example, the ultrasonic output from the segment 1144 resides within the constrained region 1152. The ultrasonic output by the segment 1146 resides within the constrained area 1154. The ultrasonic output by the segment 1148 resides within the constrained area 1156. The ultrasonic output from the segment 1150 resides within the constrained area 1158. By selectively controlling the selectable segments of the curved configuration 1142, the width of the ultrasonic output (and thus the resulting audio output) can be controlled.

[00102] Segmenting the transducer surface shown in FIG. 11B can be done by turning on elements in the different segments. To illustrate, referring to FIG.

10A, a subset of the ultrasonic elements 1004 can be activated. For example, the spherical emitter is shown as having sixty-four (64) ultrasonic elements 1004, which can be bimorph devices. A smaller beam could be emitted if, for example, only the interior sixteen (16) ultrasonic elements were utilized.

[00103] Still further, the propagation direction of the ultrasonic beam, such as the beam 1006 in FIG. 10A, the beam 1040 in FIG. 10B or the beam 1106 in FIG. 11A, can be changed by electrical and/or mechanical mechanisms. To illustrate based on the spherical-shaped ultrasonic speaker shown in FIG. 10A, a user can physically reposition the spherical surface 1002 to change its beam's orientation or direction. Alternatively, a motor can be mechanically coupled to the spherical surface 1002 to change its orientation or the propagation direction of the ultrasonic output. In yet another embodiment, the direction of the beam can be changed electronically based on phase array techniques.

[00104] The movement of the spherical surface 1002 to adjust the delivery direction can track user movement. This tracking can be performed dynamically. This can be done through different mechanisms, such as by GPS or other triangulation techniques. The user's position is fed back to or calculated by the directional audio apparatus. The position can then become a beam attribute input. The beam-attribute control unit would convert the input into the appropriate control signals to adjust the delivery direction of the audio output. The movement of the spherical surface 1002 can also be in response to a user input. In other words, the movement or positioning of the beam 1006 can be done automatically or at the instruction of the user.

[00105] FIGs. 12A and 12B are perspective diagrams of one embodiment of directional audio apparatus that provides directional audio output to interested users. FIG. 12A illustrates a directional audio apparatus 1200 that includes an entertainment center, such as a television 1202, a set-top box 1204 and a directional speaker 1206. The television 1202 displays video that is supplied, for example, by a satellite link or a cable line via the set-top box 1204. Typically, the set-top box 1204 operates to decode the encoded video and audio content transmitted over the satellite link or cable line. Once decoded, the appropriate

audio and video signals are delivered to the television 1202. The television 1202 may include conventional or normal speakers to provide audio output. These speakers typically do not produce audio output through generating ultrasonic signals to be converted into the audio frequency range by interaction with air. Nevertheless, the audio apparatus 1200 includes the directional speaker 1206. The directional speaker 1206 provides delivery of audio signals in a constrained direction. Further, the directionally-constrained audio outputs can be controlled as to the target distance for its users as well as for the width of the resulting audio beam. The directional speaker 1206 generates ultrasonic output by way of an emitter surface 1208. The emitter surface 1208 can include a single or multiple segments of groups of ultrasonic or speaker elements.

[00106] Furthermore, the directional speaker 1206 is mounted to the set-top box 1204 such that its position can be adjusted with respect to the set-top box 1204 as well as the television 1202. For example, the directional speaker 1206 can be rotated to cause a change in the direction in which the directionally-constrained audio output outputs are delivered. In one embodiment, a user of the audio system 1200 can manually position (e.g., rotate) the directional speaker 1206 to adjust the delivery direction. In another embodiment, the directional speaker 1206 can be positioned (e.g., rotated) by way of an electrical motor provided within the set-top box 1204 or the directional speaker 1206. Such an electrical motor can be controlled by a conventional control circuit and can be instructed by one or more buttons provided on the set-top box 1204, the directional speaker 1206 or a remote control device.

[00107] FIG. 12B is a diagram of another directional audio apparatus 1220 in a set-top box environment according to another embodiment of the invention. The audio apparatus 1220 includes an entertainment system, such as a television 1222, a set-top box 1224 and a directional speaker 1226. The set-top box 1224 is typically coupled to a satellite link or a cable line to receive audio and video signals. The set-top box 1224 decodes the audio and video signals and supplies the resulting audio and video signals to the television 1222. The television 1222 displays the video signals and may use its conventional speakers

to output audio sound. However, when directional delivery of audio sound is desired, the conventional speakers of the television 1222 are not utilized. Instead, the directional speaker 1226 is utilized. The directional speaker 1226, for example, can be activated by a button, switch or other means. Once activated, the directional speaker 1226 outputs the audio signals in a directionally constrained manner. In one approach, the television 1222 has an audio-output connection that is connected to the set-top box 1224. If conventional speakers are preferred, the signal line from the audio-output connection is electrically disconnected, and normal audio output is directly from the television 1222. However, in one embodiment, if directionally-constrained audio output is desired, audio signals from the television 1222 are channeled to the set-top box 1224, and normal audio output from the television 1222 is de-activated. In yet another embodiment, the volume control in the television 1222 can be turned down if directionally-constrained audio outputs are preferred.

[00108] Still further, the set-top box 1224 and/or the directional speaker 1226 can permit control over the distance and/or width of the audio output to be transmitted to the one or more interested users. In this embodiment, the position of the directional speaker 1226 is fixed relative to the set-top box 1224. In one embodiment, the directional speaker 1226 is affixed to the set-top box 1224. In another embodiment, the directional speaker 1226 is integral with the set-top box 1224. In any case, the direction for the directionally-constrained audio output outputs can be electrically controlled through a variety of different techniques. One technique is to activate only certain segments of the emitting surface 1228 of the directional speaker 1226. Another technique is to utilize beam-steering operations based on phase control inputs.

[00109] The directional audio apparatuses 1200 and 1220 illustrated in FIGs. 12A and 12B can utilize the various methods and processes discussed above. The set-top boxes with directional speakers shown in FIGs. 12A and 12B are able to transform conventional audio systems in televisions into audio systems having directional audio delivery as explained in the present invention.

[00110] To illustrate, the directional speaker with the emitting surface 1140 shown in FIG. 11B can be used as the emitting surface 1228 for the directional speaker 1226 illustrated in FIG. 12B. For example, initially only the segment 1146 is in operation. The user signals the set-top box that its beam width should be increased. Then the segment 1148 can be additionally activated, thereby increasing the width or area associated with the ultrasonic output (and thus resulting audio outputs). In yet another application, non-adjacent segments can be simultaneously activated to generate multiple separate beams. For example, a user can signal the set-top box to activate the two outer most beams, 1152 and 1158. This will generate two separate beams for two separate users. Then, a person located in the middle between the two users would only hear a substantially reduced output level.

[00111] In another example, more than one user are sitting close to the television 1200 in FIG. 12A. It would be advantageous to have a wider beam that covers a shorter distance. One embodiment uses a directional speaker 1206 that operates at a higher frequency, such as the one shown in FIG. 9G, working at 200 kHz. The beam width is broader than the version shown in FIG. 9E, but the beam covers a shorter distance due to higher attenuation.

[00112] FIG. 13 is a perspective diagram of a remote control device 1300 according to one embodiment of the invention. The remote control device 1300 is one embodiment for a directional audio apparatus. The remote control device 1300 has a top surface 1302 with a plurality of buttons 1304 as is common with remote controllers. Some of these buttons 1304 can correspond to various options a user might request of a directional audio apparatus via a remote control device. Examples of these options include start, stop, play, channels, volume, etc. In one embodiment, the remote control device 1300 also includes options for the beam attribute inputs, such as discrete sizes of beam width (e.g., large, medium and small), and discrete distance coverage (e.g., long, medium and short).

[00113] The remote control device 1300 can also include a directional speaker 1306 that produces directional audio delivery to one or at most a few

users desirous of hearing the audio output. The directional speaker 1306 can be substantially flush or recessed with respect to the top surface 1302. In any case, a grating 1308 can optionally be provided over the directional speaker 1306. Still further, the directional speaker can be mounted at an angle with respect to the top surface 1302, or can be movably mounted with respect to the top surface 1302 so that the direction of delivery can be manipulated. Alternatively, a thin layer of material (e.g., plastic housing) can cover the directional speaker 1306 to provide protection, if required, yet still allow sound to pass through. Additional details on the directional speaker 1306 can be found in U.S. Patent Application No. ____, filed ____ and entitled "DIRECTIONAL WIRELESS COMMUNICATION SYSTEMS", which is hereby incorporated herein by reference. A wireless link window 1310 provides a window through which the remote control device 1300 is able to communicate in a wireless manner (e.g., radio or optical) with an audio system, which may or may not have directional audio capability. Audio signals can then be received and directed to one or at most a few users proximate to the remote control device 1300 via the directional speaker 1306.

[00114] Depending on the power level of the ultrasonic signals, sometimes, it might be beneficial to reduce its level in free space to prevent any potential health hazards, if any. FIGs. 14A-14B show two such embodiments that can be employed, for example, for such a purpose. FIG. 14A illustrates a directional speaker with a planar emitting surface 1404 of ultrasonic output. The dimension of the planar surface can be much bigger than the wavelength of the ultrasonic signals. For example, the ultrasonic frequency is 100 kHz and the planar surface dimension is 15 cm, which is 50 times larger than the wavelength. With a much bigger dimension, the ultrasonic waves emitting from the surface are controlled so that they do not diverge significantly within the enclosure 1402. In the example shown in FIG. 14A, the directional audio delivery device 1400 includes an enclosure 1402 with at least two reflecting surfaces for the ultrasonic waves. The emitting surface 1404 generates the ultrasonic waves, which propagate in a beam 1406. The beam reflects within the enclosure 1402 back and forth at least

once by reflecting surfaces 1408. After the multiple reflections, the beam emits from the enclosure at an opening 1410 as the output audio 1412. The dimensions of the opening 1410 can be similar to the dimensions of the emitting surface 1404. In one embodiment, the last reflecting surface can be a concave or convex surface 1414, instead of a planar reflector, to generate, respectively, a converging or diverging beam for the output audio 1412. Also, at the opening 1410, there can be an ultrasonic absorber to further reduce the power level of the ultrasonic output in free space.

[00115] FIG. 14B shows another embodiment of a directional audio delivery device 1450 that allows the ultrasonic waves to bounce back and forth at least once by ultrasonic reflecting surfaces before emitting into free space. In FIG. 14B, the directional speaker has a concave emitting surface 1460. As explained by FIG. 10B, the concave surface first focuses the beam and then diverges the beam. For example, the focal point 1464 of the concave surface 1460 is at the mid-point of the beam path within the enclosure. Then with the last reflecting surface 1462 being flat, convex or concave, the beam width at the opening 1466 of the enclosure can be not much larger than the beam width right at the concaved emitting surface 1460. However, at the emitting surface 1460, the beam is converging. While at the opening 1466, the beam is diverging. The curvatures of the emitting and reflecting surfaces can be computed according to the desired focal length or beam divergence angle similar to techniques used in optics, such as in telescopic structures.

[00116] More than one directional audio delivery device can be employed to provide stereo effects. FIG. 15 shows one such embodiment as illustrated by a building layout 1500. An audio system 1506 is coupled to two directional audio delivery devices 1502 and 1504 that are spaced apart. In one approach, the audio system transmits different types of audio signals, either wireline or wirelessly, to the two directional audio delivery devices 1502 and 1504. For example, the different types of audio signals can represent a left channel and a right channel. The two directional audio delivery devices 1502 and 1504 generate two directionally-constrained audio output beams 1510 and 1512 that

are directed towards and received by a user 1508. Note that the number of directional audio delivery devices does not have to be limited to two. For example, a surround sound arrangement can be achieved through more than two directional audio delivery devices.

[00117] The various embodiments, implementations and features of the invention noted above can be combined in various ways or used separately. Those skilled in the art will understand from the description that the invention can be equally applied to or used in other various different settings with respect to various combinations, embodiments, implementations or features provided in the description herein.

[00118] The invention can be implemented in software, hardware or a combination of hardware and software. A number of embodiments of the invention can also be embodied as computer readable code on a computer readable medium. The computer readable medium is any data storage device that can store data which can thereafter be read by a computer system. Examples of the computer readable medium include read-only memory, random-access memory, CD-ROMs, magnetic tape, optical data storage devices, and carrier waves. The computer readable medium can also be distributed over network-coupled computer systems so that the computer readable code is stored and executed in a distributed fashion.

[00119] The advantages of the invention are numerous. Different embodiments or implementations may yield different advantages. One advantage of the invention is that audio output from a directional audio apparatus can be directionally constrained so as to provide directional audio delivery. The directionally-constrained audio output can provide less disturbance to others in the vicinity who are not desirous of hearing the audio output. A number of attributes of the constrained audio outputs can be adjusted, either by a user or automatically and dynamically based on certain monitored or tracked measurements, such as the position of the user.

[00120] One adjustable attribute is the direction of the constrained audio outputs. It can be controlled, for example, by (a) activating different segments of

a planar or curved speaker surface, (b) using a motor, (c) manually moving the directional speaker, or (d) through phase array beam steering techniques.

[00121] Another adjustable attribute is the width of the beam of the constrained audio outputs. It can be controlled, for example, by (a) modifying the frequency of the ultrasonic signals, (b) activating one or more segments of the speaker surface, (c) using phase array beam forming techniques, (d) employing curved speaker surfaces to diverge the beam, (e) changing the focal point of the beam, or (f) de-focusing the beam.

[00122] The degree of isolation or privacy can also be controlled independent of the beam width. For example, one can have a wider beam that covers a shorter distance through increasing the frequency of the ultrasonic signals. Isolation or privacy can also be controlled through, for example, (a) phase array beam forming techniques, (b) adjusting the focal point of the beam, or (c) de-focusing the beam.

[00123] The volume of the audio output can be modified through, for example, (a) changing the amplitude of the ultrasonic signals driving the directional speakers, (b) modifying the ultrasonic frequency to change its distance coverage, or (c) activating more segments of a planar or curved speaker surface.

[00124] The audio output can also be personalized or adjusted based on the audio conditions of the areas surrounding the directional audio apparatus. Signal pre-processing techniques can be applied to the audio signals for such personalization and adjustment.

[00125] Ultrasonic hazards, if any, can be minimized by increasing the path lengths of the ultrasonic waves from the directional speakers before the ultrasonic waves emit into free space. There can also be an ultrasonic absorber to attenuate the ultrasonic waves before they emit into free space. Another way to reduce potential hazard, if any, is to increase the frequency of the ultrasonic signals to reduce their distance coverage.

[00126] Stereo effects can also be introduced by using more than one directional audio delivery devices that are spaced apart. This will generate multiple and different constrained audio outputs to create stereo effects for a user.

[00127] Directionally-constrained audio output outputs are not limited to be generated by set-top boxes. They can also be generated from a remote control.

[00128] Numerous embodiments of the present invention have been applied to an indoor environment, using building layouts. However, many embodiments of the present invention are perfectly suitable for outdoor applications also. For example, a user can be sitting inside a patio reading a book, while listening to music from a directional audio apparatus of the present invention. The apparatus can be outside, such as 10 meters away from the user. Due to the directionally constrained nature of the audio output, sound can still be localized within the direct vicinity of the user. As a result, the degree of noise pollution to the user's neighbors is significantly reduced.

[00129] Finally, an existing audio system can be modified with one of the described set-top boxes to generate directionally-constrained audio output outputs. A user can select either directionally constrained or normal audio outputs from the audio system, as desired.

[00130] Numerous specific details are set forth in order to provide a thorough understanding of the invention. However, it will be understood by those skilled in the art that the invention may be practiced without these specific details. The description and representation herein are the common meanings used by those experienced or skilled in the art to most effectively convey the substance of their work to others skilled in the art. In other instances, well-known methods, procedures, components, and circuitry have not been described in detail to avoid unnecessarily obscuring aspects of the present invention.

[00131] In the foregoing description, reference to "one embodiment" or "an embodiment" means that a particular feature, structure, or characteristic described in connection with the embodiment can be included in at least one

embodiment of the invention. The appearances of the phrase "in one embodiment" in various places in the specification are not necessarily all referring to the same embodiment, nor are separate or alternative embodiments mutually exclusive of other embodiments. Further, the order of blocks in process flowcharts or diagrams representing one or more embodiments of the invention do not inherently indicate any particular order nor imply any limitations in the invention.

[00132] The many features and advantages of the present invention are apparent from the written description and, thus, it is intended by the appended claims to cover all such features and advantages of the invention. Further, since numerous modifications and changes will readily occur to those skilled in the art, it is not desired to limit the invention to the exact construction and operation as illustrated and described. Hence, all suitable modifications and equivalents may be resorted to as falling within the scope of the invention.

What is claimed is: